

Determination of Rock Quality Designation (RQD) through Spectral Analysis Surface Wave (SASW) and Observed Method for Granitic Rock Mass

Asrillah

Malikussaleh University, Engineering Faculty, Civil Engineering Department
Corresponding Author: asril_ah@yahoo.com

Abstract. Spectral Analysis Surface Wave (SASW) and observation method were carried out at Kajang Rock Quarry Sdn. Bhd which is located in district Semenyih-Selangor. The objective of this survey is to determinate Rock Quality Designation (RQD) of the granitic rock mass quarried from terrace 9 (highest) to terrace 7. The SASW survey was conducted with using OROS 25 and the software that used for data processing is Winsasw 3.1.3. The Rock Quality Designation (RQD) for terrace 9 varies from 45.63 % to 94.17 %. Base on Suharsono rock classification system, these two values suggest that the rock mass is easy rippable and need blasting. The RQD for terrace 8 are 40.12 %, 72.43 %, 80.35 % and 99.39 % which are classified as easy rippable, hardly rippable, required hydraulic breaker and blasting. The terrace 7 has three RQD show that the rock mass requires hydraulic breaker and blasting.

Keywords: SASW, RQD, terrace, rock mass, rippable, blasting

Introduction

In early 80s, a two-receiver approach was introduced by investigators at the University Texas (UT), Austin, which was based on the Fast Fourier Transform (FFT) analysis of phase spectra of surface waves generated by using an impulsive source like the sledge hammer. It then became widely used among geotechnical engineers and researchers. This method was called Spectral Analysis of Surface Waves (SASW) (Heisey *et al.* 1982). Spectral Analysis Surface Wave (SASW) is a seismic characterisation method based on the analysis of the *geometric dispersion of surface waves*, by which the vertical distribution of the dynamic shear modulus in the subsoil can be obtained: the procedure consists of estimating the dispersive characteristics at a site, (by means of *acquisition* and *processing* of seismic data), and then of *inverting* these data to estimate the subsoil properties. The obtained result is the vertical profile of the shear wave velocity. The use of Rayleigh wave allows a simpler acquisition and is widely more diffused than that of Love Waves (Strobbia, 2003).

The SASW test method is a non-destructive and nonintrusive seismic method. The method utilizes the dispersive nature of Rayleigh-type surface waves propagating through a layered material to determine the shear wave velocity profile into the material (Stokoe *et al.*, 1994). In this context, dispersion arises when surface wave velocity varies with wavelength or frequency. Dispersion in surface wave velocity arises from changing stiffness properties of the soil and rock layers with depth. A high-frequency surface wave, which propagates with a short wavelength, only stresses material near the exposed surface and thus only samples the properties of the shallow, near-surface material. A lower-frequency surface wave, which has a longer wavelength, stresses material to a greater depth and thus samples the properties of the shallower and deeper materials. Spectral analysis is used to separate the waves by frequency and wavelength to determine the experimental ("field") dispersion curve for the site. An analytical procedure is then used to theoretically match the field dispersion curve with a one-dimensional layered system of varying layer stiffnesses and thicknesses (Joh, 1996). The one-dimensional shear wave velocity profile that generates a dispersion curve which matches the field dispersion curve is presented as the shear wave velocity profile at the site (Stokoe *et al.*, 1994).

This research was carried out on three terraces in Kajang Rock Quarry Sdn. Bhd, Semenyih-Selangor Malaysia. Its objective is determination of Rock Quality Designation (RQD) for granitic rock mass. Determination RQD aims to classify the rock with what are kind of ways for breaking its. Rock quality designation RQD was introduced by (Deere, 1964) as an index of assessing rock quality quantitatively. It is a more sensitive index of the core quality than the core recovery. The RQD is a modified percent core-recovery which incorporates only sound pieces of core that one 100 mm (14 inches) or greater in length along the core aims (Singh & Gole, 1999).

For direct measurement of discontinuity on slope surface can be roughly used as a reference (Deere, 1968) that seen in equation (1) below:

$$RQD = \frac{\text{Accumulative length of sample core} > 10\text{cm}}{\text{Total length of drilling}} \times 100 \% \quad (1)$$

and also suggested relationships between RQD and classification of rock quality which listed in Table 1 :

Table 1. Relationships between RQD and its classification.

RQD (%)	Classification
0 – 25	Very por
25 -50	Poor
50 – 75	Fair
75 -90	Good
90 – 100	Excellent

For more accuracy to determine RQD is using an empirical equation that base on Suharsono et al (2004). The equation is stated below:

$$RQD = 100^{(1-\delta)} \quad (2)$$

where, $\delta = \left[\frac{(V_{S\mu} - V_{S\beta})^2}{(V_{S\mu} + V_{S\beta})^2} \right]^2$, $V_{S\mu}$ is shear wave velocity of ultrasonic test and $V_{\mu\beta}$ is shear wave velocity of SASW test.

Materials and Methods

Equipment

This research was equipped by several equipment. They are spectrum analysis, OR25 PC-Pack II, battery 12 V, geophone/receiver (model: L 22D, frequency 2 Hz, sensitivity 1 V/ m/s), velocity transducer (model: A/123/TE; frequency 50 kHz; sensitivity 10 mV/g), geophone cable, hammer in various sizes, terminal cable, battery charger, laptop, tape measure, iron plate and AC-DC inverter. The general setting of equipment is viewed in Figure 1.

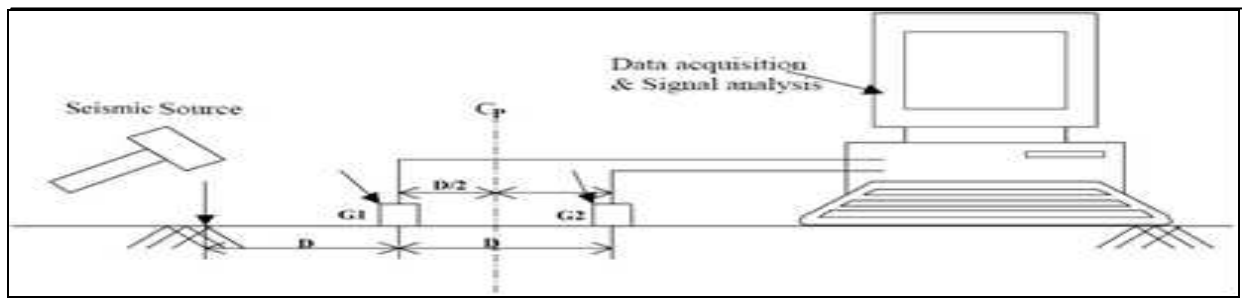


Figure 1. The general setting of equipment (Source: Modified from Khanna & Mooney, 1999).

General SASW Procedure

1. Field Testing Configuration

The field testing configuration was setting on each terrace. It is started from terrace 9 (highest terrace) to terrace 7. Each of terraces has a seismic total length 16 m and also has four separated geophones. These are 1 m, 2 m, 4 m and 8 m. Therefore, each of seismic line has four shots as seismic sources which are forward/normal shots. The field configuration can be shown in figure 2 below:

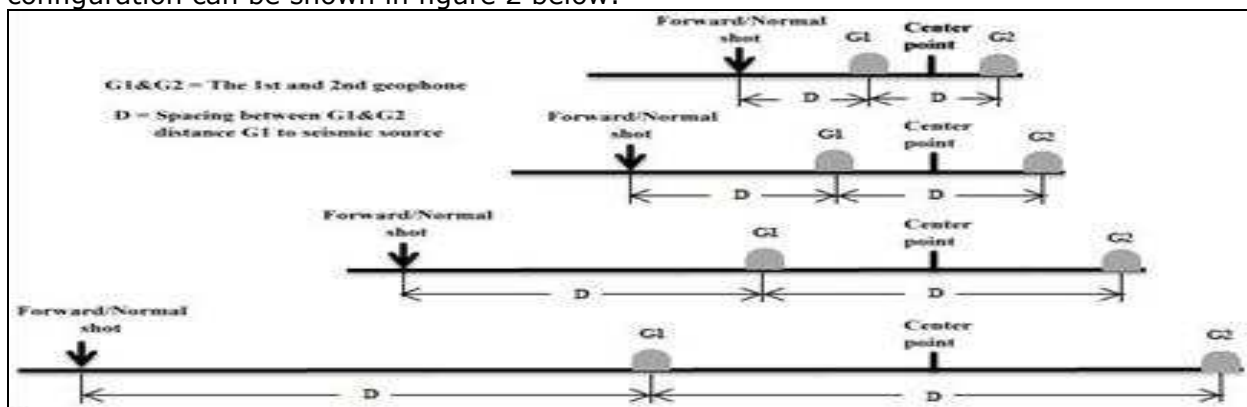


Figure 2. Configuration of seismic line.

2. Data processing for dispersion curve

Data processing technique is another advantage of the SASW method. The accurate near surface profile (1D Vs. profile) can be obtained by using a proper technique of dispersion and inversion processes. Images of dispersion curve can be converted directly from multi-channel record using several methods (Ariestianty *et al.*, 2008). The phase shift method (Park *et al.*, 1998) is a method that can construct images of dispersion curve with higher resolution and need relatively small number of traces. The transformation of raw data to form images of dispersion curve is employed by Fourier transformation and an integral transformation. With these transformations, the data is changed from offset-time domain to frequency-phase velocity-amplitude domain where the seismic events can be clearly identified

3. Inversion process

Inversion process is the last step in the processing multi-channel method in order to generate the shear wave velocity profile. The accuracy of dispersion curve will enhance the inversion calculation. Many inversion methods have been proposed to invert a dispersion characteristic to obtain the soil stiffness profile. One of the methods is the least squares method. The inversion process is started by assuming an initial earth layer model. Subsequently, the theoretical dispersion curve of the earth layer model, calculated by Knopoff's method, is compared with the experimental dispersion curve to get the most fitted dispersion curve. The shear wave velocity is analysed and inverted using the Jacobian matrix, using the Levenberg-Marquardt (L-M) and singular value decomposition (SVD)

technique (Xia *et al.*, 1999). The damping factor of L-M method improves the speed of the convergence procedure and the damping factor changes without recalculating the inverse matrix using SVD technique. This method has resulted in a fast and stable calculation to invert the dispersion curves (Ariestianty *et al.*, 2008). A flow chart of data processing is look like below:

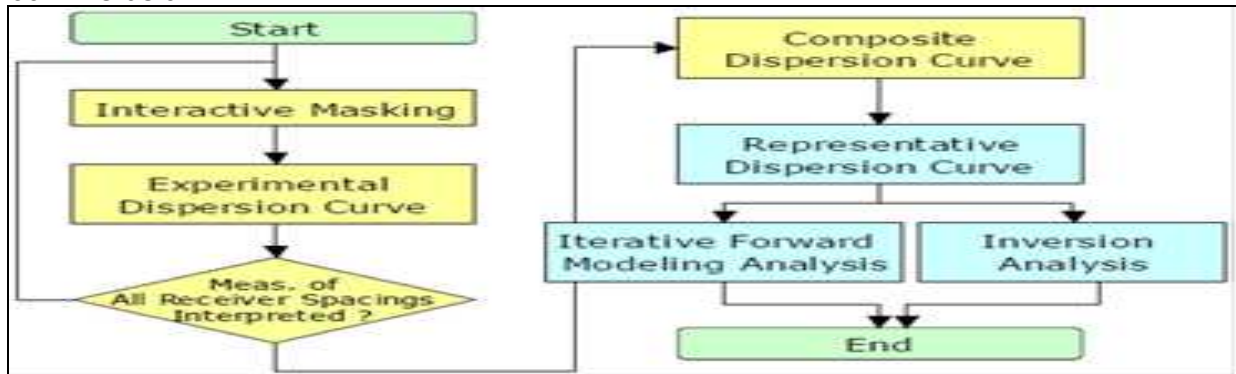


Figure 3. Data Interpretation and Analysis Procedure of SASW Measurements (Source: Winsas 2.0, 2002).

4. Laboratory measurement

After the SASW test was completed, three chunks of granitic rock as representative of each terrace were brought back for ultrasonic testing at laboratory. The ultrasonic testing wants to know shear wave velocity that travels through a cored sample. Before the ultrasonic testing is done, all the chunks of granitic rock mass are drilled using drilling machine for making core of rock sample which has a cylindrical shape. Each of samples has same size that is 110 m in length and 55 mm in diameter. Therefore, all of sample cores are tested using PUNDIT (*Portable Ultrasonic Non Destructive Indicating Tester*).

Results and Discussion

The data of SASW testing shows that all of terraces roughly have four layers which indicated by velocity contrast that against depth. This relationship for all terraces can be seen on one dimensional (1 D) profile on Figure 4a, 4b and 4c. According to equation (2), therefore the values of RQD for all terraces can be calculated. They are can be shown in Table 2.

In detail view about figures 4a, 4b and 4c above are all of them point out that shear wave velocity on all terraces gradually increases together with increasing depth. It roughly means more increasing the depth, and then stiffness of granitic rock mass is also more increase. This is quietly estimated which caused by compaction between rocks because rocks tend to form as homogenous layers and that is commonly happening in rock cases, but it is commonly not for soil cases. In view of terrace by terrace, the terrace 9 (figure 4a) shows that has four layers which indicated by green colour. The first layer has around 2.15 m depth and 707.7 m/s. The second layer is located at 6.18 m depth and has 1608.94 m/s. The third and fourth layer are located at 13.18 m and 16.18 m. They have approximately same of shear wave velocity that are around 1681.15 m/s and 1681.45 m/s. These two last layer have a constant shear wave velocity that indicates they have appropriately a mechanical properties. The terrace 8 and terrace 7 also have four layers that can details be seen in figure 4b and 4c then the shear wave velocity graph also have a same trend with the terrace 9, but they are different in values.

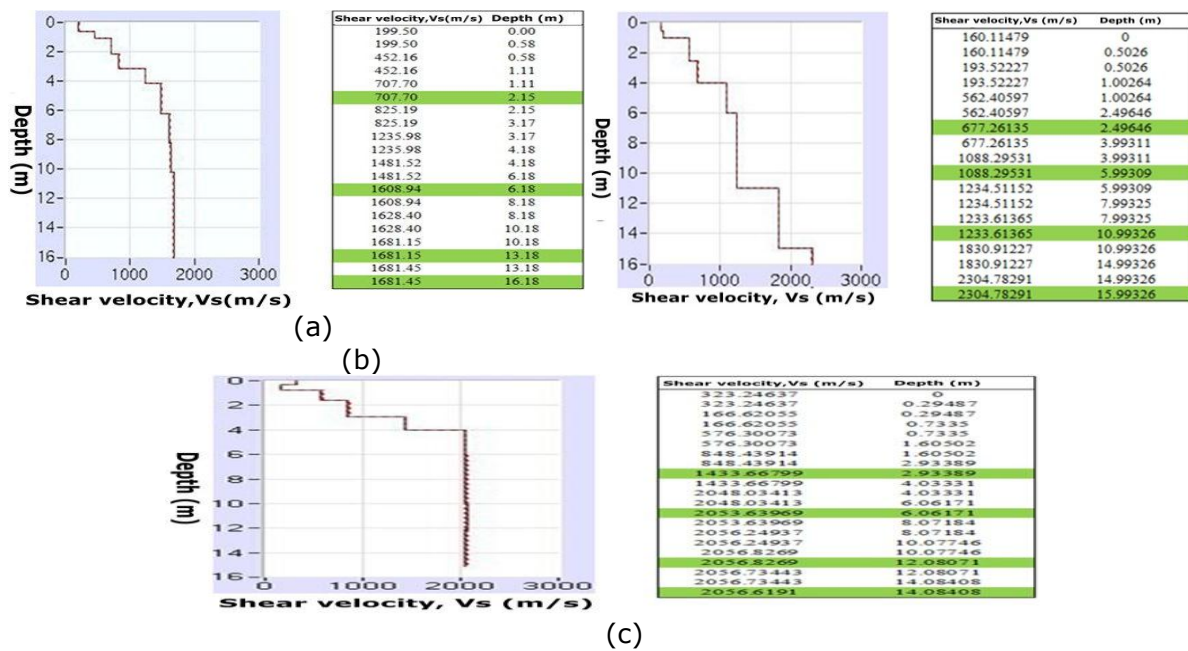


Figure 4. One dimensional (1D) profile of shear wave velocity (V_s) against depth (a) terrace 9 (b) terrace 8 and (c) terrace 7.

Table 2. Value and its average of RQD for terrace 9, 8 and 7.

Terrace	Layer No	H (m)	V_s SASW (m/s)	V_s Average ultrasonic (m/s)	RQD SASW (%)	RQD SASW Average (%)
9	1	2.15	707.7	2837.54	45.63	83.79
	2	6.18	1608.91		94.17	
	3	13.18	1681.15		97.69	
	4	16.18	1681.45		97.69	
8	1	2.49	677.26	2941.21	40.12	73.07
	2	5.90	1088.29		72.43	
	3	10.9	1233.61		80.35	
	4	15.9	2304.78		99.39	
7	1	2.93	1433.66	3286.89	87.00	95.24
	2	6.06	2053.63		97.97	
	3	12.08	2056.82		97.99	
	4	14.08	2056.61		97.99	

Table 2 shows that averages of RQDs for every terrace are commonly increase gradually. Even though RQD of the terrace 8 (73.07 %) decreases if we compare with average RQD's terrace 9 (83.79 %) and RQD's terrace 7 (95.24 %) then the RQD's terrace 7 is greater than RQD's terrace 9 and 8. This data indicate that stiffness of granitic rock mass of terrace 7 greatest than terrace 9 and 8, so that the stiffness of granitic rock mass from greatest to lowest in series is terrace 7, 9 and 8. Furthermore, it involves that on the terrace 8 has many discontinuities or cracks and cracks than the others, even the terrace 8 is located below of the terrace 9. The terrace 9 is a highest terrace that means located on the top of the quarry. The highest terrace most expose than the terrace that located below it, so that the exposed terrace is easier change that influenced by weather. The discontinuities is also influenced by weathered condition of rock because a weathered rock is easier going to be discontinuities or cracks, fractures and fissures. In the other hand, discontinuities are also caused by surrounding pressure and that is quite possible happened in terrace 8. Finally, that will effect to the RQD values. For the result of RQD from direct measurement can be obtained from measurement the discontinuity of slope surface. The three slope surfaces as we can see in figure 5 where they have a different total length. The total length of the first slope (located between terrace 9 and 8) is 12.5 m and the total

length of the second slope (located between terrace 8 and 7) is 13 m then the final slope (located between terrace 7 and 6) has 13.4 m total length. Using the equation (1), so the RQD of them can be calculated that listed in table 3 below:

Table 3. RQD values from direct measurement of slope surfaces.

Terrace	Total length of Slope surface (m)	Sum length < 10 cm Of slope surface (m)	RQD (%)
9	12.5	2.81	77.52
8	13	3.87	70.32
7	13.4	1.7	87.31

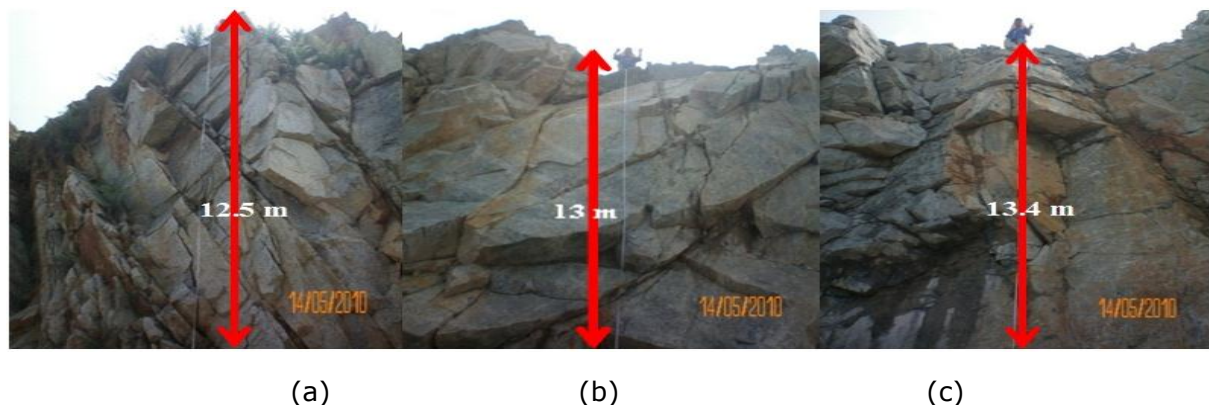


Figure 5. Direct measurement of discontinuity on the slope surface (a) terrace 9, (b) terrace 8 and (c) terrace 7.

The table 3 shows that RQD values have a same trend with the trend that assessed by SASW method. This similarity indicates that both SASW and observed method can be applied. The RQD values from terrace 9 to terrace 7 are 77.52 %, 70.32 % and 87.31 %. If we compare the RQD value that resulted by SASW and observed method show that all of them are different. For example, the RQD from SASW and observed method for terrace 9 is 83.79 % and 77.52 %. This difference is 6.27 % and it is reliable because this difference is below of 10 % and so does the values of RQD for terrace 8 and 7. The observed method has a weakness, because the measurement of discontinuities on slope surface is roughly conducted. This reason is caused by limited access when measuring from the top to bottom of slope, so that this method less accurate than SASW method.

Furthermore, the RQD values can be classified in a final term that serve as references for rock classification system in term of rippable need. For classification of granitic rock mass in Kajang Rock Quarry is listed in Table 4.

Table 4. Rippable classification of granitic rock mass Kajang Rock Quarry

RQD range (%)	Type of rippability	Vs. SASW/ Vs. Ultrasonic	Vs. SASW (m/s)
0 - 25	Rippable	0 - 0.10	0 - 350
25 - 50	Easy rippable	0.10 - 0.15	475 - 707
50 - 75	Hardly rippable	0.15 - 0.20	707.7 - 1200
75 - 90	Hidraulic breaker	0.20 - 0.25	1200 - 1800
90 - 100	Blasting	0.25 - 0.34	1800 - 2673

The table 4 involves that there are five types of rippable classification of granitic rock mass. The first type has RQD range 0-25 % and shear wave velocity (Vs.) = 0-350 m/s, so that this type classified as rippable (top soil). The second type is has RQD range 25-50 % and vs. = 475-707.7 m/s and classified easy rippable. This type has 80 % weathered rock. The third type has RQD range 50-70 % and vs. = 707.7-1200 m/s. This type is called hardly rippable. The remaining types can refer to table 4. All of RQD values

above deeply tell us that together with increasing depth, so it will have shear wave velocity greater then it also has similarity of RQD trend, it appropriately means that the shear wave velocity is linier with RQD value.

These two methods are very helpful in term of geotechnical investigation. Classification of RQD values is very useful and as input for geotechnical engineers in behalf of to build underground building like tunnel, subway and other near and subsurface constructions. Other applications of SASW method are to identify other geotechnical cases for example, determining bearing capacity, identifying liquefaction phenomenon, locating sinkhole, and knowing of a thickness sub-grade and pavement, etc.

Conclusions

Base on result and discussion, it can be summarized several points which listed below:

1. The Rock Quality Designation (RQD) for terrace 9 varies from 45.63% to 94.17%.
Base on Suharsono rock classification system, these two values suggest that the rock mass is easy rippable and need blasting.
2. The RQD for terrace 8 are 40.12 %, 72.43 %, 80.35 % and 99.39 % which are classified as easy rippable, hardly rippable, required hydraulic breaker and blasting.
3. The terrace 7 has three RQD show that the rock mass requires hydraulic breaker and blasting.
4. The RQD value is one of important thing in term of planning for underground constructions.
5. The SASW and observed method are approximately having a closed result, but the SASW method is more accurate.
6. The SASW method is very useful in geotechnical investigation cases, for example identifying liquefaction phenomenon, determining bearing capacity, knowing a thickness of subgrade and pavement, locating sinkhole, mapping subsurface stratigraphy, etc.

Acknowledgements

My deepest gratitude for my supervisors, especially for Prof. Abd. Rahim Samsudin, Prof. Umar Hamzah, my research partners, all of my classmates, my lovely families and whoever because they encouraged or supported and motivated my research and writing, so that I am really thankful to them.

References

- Ariestianty S.K., Taha M.R., Nayan K.A.M., Zamri C., Rosyidi S.A. 2008. *Engineering Postgraduate Conference*. Department of Civil and Structural Engineering, National University of Malaysia, Malaysia.
- Deere D.U. 1964. Technical Description of Cores for Engineering Purpose. *Rock Mechanics Engineering Geology*, 1: 16-22.
- Deere D.V. 1968. *Geological Consideration, Rock Mechanics in Engineering Practice*. Wiley, New York.
- Joh S.-H. 1996. Advances in Interpretation and Analysis Techniques for Spectral-Analysis-of-Surface-Waves (SASW) Measurements, Ph.D. Dissertation. The University of Texas at Austin.
- Khanna V. & Mooney M. A. 1999. Comparison of back-calculated SASW profiles with results from coring and DCP testing. School of Civil Engineering and Environmental Science, University of Oklahoma, USA.
- Singh B. & Goel R. K. 1999. *Rockmass classification - a practical approach in civil engineering*. Elsevier Science Publishing Co, Amsterdam.
- Strobbia C. 2003. Surface Wave Methods Acquisition, processing and inversion. Politecnico, Torino. Italy.
- Stokoe. K.H., II, Wright S.G., Bay, J.A., Roesset J.M. 1994. Characterization of Geotechnical Sites by SASW Method. *ISSMFE Technical Committee 10 for XIII ICSMFE*. Geophysical Characteristics of Sites, A.A. Balkema Publishers/Rotterdam & Brookfield, Netherlands, pp. 785-816.
- Suharsono & Samsudin A.R. 2004. Penggunaan Kaedah Analisis Spektral Gelombang

- Permukaan sebagai Teknik baru untuk Pengelasan Jasad Batuan Dalam Geologi
Kejuruteraan, thesis Ph. D. Universiti Kebangsaan Malaysia.
- User's guide Winsas 2.0. 2002. Data Interpretation and Analysis for SASW Measurement.
Chung-Ang University, Anseong, Korea.
- Park C.B., Miller, R.D., Xia, J. 1998. Imaging dispersion curves of surface waves on multi-
channel record: [Expanded Abstract]: Social Exploration Geophysics., 1377-1380.
- Xia J., Miller R.D., Park C.B. 1999. Estimation of near-surface shear-wave velocity by
inversion of Rayleigh waves. Geophysics, v.64, no.3, p.691-700.